The Open University

S102PRP/S510 MODULE 4 INTO SCIENCE

MODULE 4 THE SIZE OF THINGS

STUDY GUIDE

This Module gives you an insight into the scale that science encompasses in terms of both time and distance and demonstrates a convenient way of representing this variation of scale mathematically. In addition, there is a small piece of practical work for you to carry out that involves measuring the size of a water droplet. In total the Module should take you between three and four hours to study.

Modules 1 to 3 gave you some practice in basic arithmetic using your calculator. This Module extends these mathematical skills to include the use of another key on your calculator: the EXP or EE key.

The main aim of the Module is to continue to develop your mathematical skills; in working through the Module you should concentrate on understanding the mathematical notation and calculations, rather than the scientific concepts. The scientific content of this Module is included for your interest only; you are not expected to remember the details.

The only equipment you will need is a scientific calculator and a small measuring spoon (5 ml) for the practical work to measure the size of a water droplet. You will also need access to a tap that can be made to drip slowly.

1 INTRODUCTION

Science is all about answering questions about our lives and the world we live in, such as: How far is it to the Sun? When did the Earth come into being? How fast do an insect's wings flutter? To be able to consider questions such as these we need to appreciate the different sizes and distances involved.

The first part of this Module deals with time and how it is measured. It begins by considering the huge span of time from the moment at which the Earth is thought to have come into existence and then goes on to look at much shorter time periods, such as the time taken for the rapid movements of an insect's wings.

The later parts of the Module focus on the size of things—of the **Universe** and the vast distances involved and, at the other extreme, of the smallest particles known to exist. By the end of the Module, you will have discovered the answers to at least some of the questions mentioned above.

The excitement of science is that the number of questions we can ask is endless: the more we find out, the more we want to know.

2 TIME

Many millions of years have passed since the Earth came into existence, and changes to our **planet** have occurred very slowly since its beginning. This enormous span is called **geological time**, and covers the whole of the evolution of Earth and life on Earth as we know it. Before going on to look briefly at geological time, this Section considers what is meant by time itself.

It is easy to call the interval between one sunrise and the next a day, or the time between one spring and the next a year. Both these concepts of time are very familiar to us; but where do the terms come from? To explain these measurements of time it is necessary to look at the way in which the Earth moves round the Sun.

Figure 1 shows the nearly circular path that the Earth follows in its journey around the Sun. One complete journey around the Sun takes the Earth about 365 days—the time period understood to be a year. At the same time as moving around the Sun, the Earth spins at a constant rate, very much like a spinning top. The time taken for it to complete one revolution gives us another measure of time—a day.

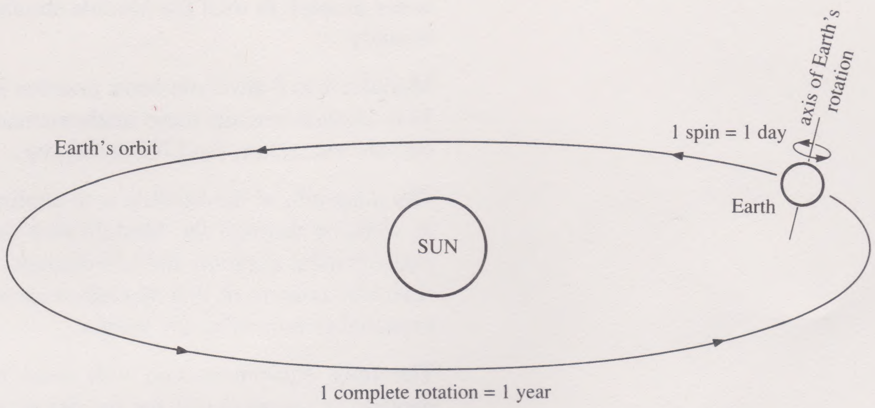

FIGURE 1 The relative positions and movements of the Earth and the Sun.

In contrast to the time periods such as the year and the day, the week has no natural origin: the seven days are named after the seven heavenly bodies recognized by the ancients and the gods who supposedly ruled them. Saturday therefore derives from Saturn's day, Sunday from the Sun's day, and Monday from the Moon's day. The remaining names are from the Germanic equivalents of the Latin names, so Tuesday was from Tiw's (Mars') day, Wednesday from Woden's (Mercury's) day, Thursday from Thor's (Jupiter's) day and Friday from Freya's (Venus') day. The basis of our measurement of time is thus quite simple: the day and the year both reflect intervals between astronomical events, and the week is of mystical origin. This is all very well, but how do we actually tell the time? The passage of time can be assessed in a qualitative way (look back at Module 2 if you are uncertain about the meaning of qualitative), by observing an event that occurs on a regular basis. The event may be the rising and setting of the Sun, or the passage of time from spring to spring. In an attempt to measure time more accurately, humans have invented mechanical and electronic clocks. These divide the passage of time into equal intervals that can be measured. Dividing time into hours, minutes and seconds has been done for centuries. But when did time begin? To answer this question it is necessary to decide on an event from which time can be measured. The next Section looks at the idea of starting the clock when the Earth came into existence.

2.1 GEOLOGICAL TIME

Before considering *when* the Earth came into existence, let us begin by thinking about *how* this happened. Scientists currently believe that the Universe began some ten thousand million years ago, when an enormously dense, hot mass suddenly exploded. Gas, dust and a huge amount of energy were hurled out into space. This explosion is now referred to as the Big Bang. As time went on the matter came together in individual groups called **galaxies**. Our own **Galaxy**—that is, the group to which our **Solar System** belongs—is called the **Milky Way**, and it is just one of the groups of stars that have evolved from the time of the Big Bang. In each of the galaxies there was a further splitting up of matter, which slowly gave rise to the stars, some of them having their own planets. Earth is just one of the planets within our Solar System. The Sun is our star, at the centre of the Solar System, and around which Earth and the other planets circle. If you look up into the sky on a clear night you can see within our Milky Way lots of other stars, all of which may have planets and moons just like our Solar System.

Exactly how these individual Solar Systems were formed remains unclear; you will meet the different theories that have been put forward to explain the origin of our Solar System, later in your studies. It would appear that after the Big Bang the Earth and other planets formed from clouds of gas and dust, very slowly, over millions of years.

So, how long ago did the Earth come into being? Scientists would consider four and a half thousand million years to be a good estimate. A million is one thousand thousand (written as 1 000 000), so four and a half thousand million (that is 4.5 billion) can be written as 4 500 000 000.

The Earth formed when the gases became solid rocks. The oldest known rocks are thought to have been formed about 3 750 000 000 years ago, but it took another 250 000 000 years for life to begin. It was not until 3 500 000 000 years ago that the Earth and its atmosphere were stable enough for the first living things to appear in the form of small **bacteria**. When dealing with these large numbers it becomes tedious to keep writing out all the zeros and it is very easy to start losing some of them! So scientists resort to a shorthand method known as **scientific notation**.

In scientific notation 4 500 000 000 is written as 4.5×10^9. It is pronounced as: 'four point five times ten to the power nine'. The number 9 is called a power. A power indicates that a number is to be multiplied by itself a certain number of times; for example, 10^3 means that 10 is multiplied by itself three times:

$$10 \times 10 \times 10$$

In scientific notation the number to be multiplied is always 10; consequently this notation is often described as **powers of ten** notation. Powers of ten are used in this shorthand method because multiplying a number by a power of ten involves moving the decimal point. For example, to multiply 4.5 by 10 the decimal point moves one place to the right: $4.5 \times 10 = 45$. Similarly, to multiply by 100 the decimal point moves two places to the right: $4.5 \times 100 = 450$. In scientific notation this is expressed as: 4.5×10^2

Multiplying 4.5 by more and more powers of ten can easily be represented in scientific notation, as you can see from the following sequence:

$4.5 \times 10 \times 10 \times 10$	= 4 500	$= 4.5 \times 10^3$
$4.5 \times 10 \times 10 \times 10 \times 10$	= 45 000	$= 4.5 \times 10^4$
$4.5 \times 10 \times 10 \times 10 \times 10 \times 10$	= 450 000	$= 4.5 \times 10^5$
$4.5 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$	= 4 500 000	$= 4.5 \times 10^6$
$4.5 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$	= 45 000 000	$= 4.5 \times 10^7$
$4.5 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$	= 450 000 000	$= 4.5 \times 10^8$
$4.5 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$	= 4 500 000 000	$= 4.5 \times 10^9$

In some instances, even scientists do not rigidly use scientific notation. Geologists, for example, commonly use millions (of years), i.e. 10^6, as a base, so ages of 1 million years and 999 million years are written in the form 1×10^6 years and 999×10^6 years. The age of the Earth is often presented in the form $4\,500 \times 10^6$ years, but also as 4.5×10^9 years. Biologists and chemists will often quote masses less than a kilogram as, for example, 340 g or 965 g. The powers 10^3 (kilo-), 10^6 (million or mega-) and 10^9 (giga-) are the most frequently used powers. It's never wrong to give an answer in scientific notation, but practical scientists in some disciplines don't always use it.

SAQ 1 Try expressing the numbers below in scientific notation. (Ignore the issue of significant figures for this question.)

(a) 3 750 000 000 (b) 250 000 000 (c) 650 000 (d) 4 000 000 (e) 3 000

2.2 THE EVOLUTION OF LIFE

In the preceding Section you learnt that the first very simple forms of life came into existence about 3 500 million years ago. These were followed, some 1 500 million years afterwards, by early plants which were relatives of present day seaweeds. Animals did not appear until much later and the earliest animal fossils have been found in rocks less than 600 million years old. These early animals did not have backbones (invertebrates) and included things like jelly fish, sea urchins and snails. The first animals with backbones (vertebrates) were fishes and remains have been found in rocks about 465 million years old. All these early plants and animals lived in water, but about 300 million years ago the vertebrates began to move on to the land. These creatures, known as amphibians, were early forms of frogs and newts. Next came reptiles such as the dinosaurs. Creatures took to the air about 165 million years ago at about a similar time as warm blooded mammals started to appear. Almost all the larger animals in the world today are mammals such as elephants and whales. Documented evidence of humans goes back about 50 000 years but fossil remains would lead us to believe that there have been closely related individuals for over 2 million years. It is very difficult to imagine the millions and millions of years encompassing geological time, but Table 1 attempts to give you an overview by representing the whole 4 500 million years of geological time as 1 year of our actual time. The main events through the ages are listed in the table, and the geological age shows how many million years ago the event is thought to have happened.

TABLE 1 Geological time represented in terms of one calendar year

Event	Geological age/ millions of years	Date on calendar
Origin of Earth	4 500	1 January
Oldest rocks found	3 750	10 March
First life—bacteria	3 500	29 March
Plants	2 000	26 July
Invertebrates (sea urchins)	600	16 November
First vertebrates (fish)	465	25 November
Amphibians (newts)	300	7 December
First reptiles	280	9 December
First dinosaurs	200	16 December
First birds	165	18 December
Dinosaurs extinct	65	26 December
First human-like individuals walk upright	2	31 December, in the afternoon
Our current generation (i.e. 30 years ago)		31 December, less than 0.1 seconds to midnight

The geological age of each event given in Table 1 is an estimate based on scientific observation and measurement. As with all estimates (even scientific ones), the figures can vary according to the methods used. You are not expected to remember the dates; the information is provided simply to help you get a feel for the vast range of geological time. To this end the third column of Table 1 shows where significant events in the Earth's history would have occurred if they had all taken place in a single year. You can see that, although the Earth came into existence on 1 January, the first life did not appear until 29 March; the dinosaurs appeared on 16 December but were extinct by 26 December. Human-like individuals walked upright on the afternoon of New Year's Eve, and our own life span would occupy less than the last tenth of a second of the year.

This Section has looked at the way life developed and the relative age of different groups that lived on Earth. The main purpose of the Section has been to teach you how to express large numbers by using the powers of ten notation; the next Section shows you how to perform calculations using this notation.

2.3 HANDLING POWERS OF TEN IN CALCULATIONS

All of the questions in this Section are based on the geological times of events in Table 1. Using the different times at which particular events occurred, we can demonstrate how to work with numbers written in the powers of ten notation.

GUIDED EXERCISE 1: SUBTRACTING NUMBERS THAT HAVE THE SAME POWER OF TEN

How much time passed between the appearance of the dinosaurs and that of the first birds?

Table 1 shows that the dinosaurs appeared 200 000 000 years ago, and the first birds appeared 165 000 000 years ago. The number of years between the appearance of the dinosaurs and that of the first birds can be obtained by subtracting one figure from the other:

$$\begin{array}{r} 200\,000\,000 \\ -\ 165\,000\,000 \\ \hline 35\,000\,000 \end{array}$$

Therefore the answer is that 35 000 000 years passed between the appearance of the dinosaurs and the first birds.

It can, however, be rather time-consuming to perform calculations like this. They can be done more easily by the powers of ten notation, providing that both numbers are expressed using the same power of ten. In this instance the dinosaurs appeared 200×10^6 years ago, and the first birds appeared 165×10^6 years ago.

As long as the powers of ten are the same (in this instance 6) for both numbers, the power can be ignored in the subtraction, giving: $200 - 165 = 35$ and the power is incorporated into the answer as: 35×10^6 years passed.

In scientific notation the answer is written with one digit to the left of the decimal point; this digit should *not* be zero. Hence, in this instance 35 would be rewritten as 3.5. The powers of ten are then adjusted as necessary. To change 35 to 3.5 divide by 10, moving the decimal point one place to the left. If we leave the power of ten alone, that is as 10^6, the number 3.5×10^6 is now ten times smaller than it should be. So to return to the original value, multiply by ten. This is done by increasing the power of ten by 1, that is from 6 to 7. In scientific notation our answer would be:

$$3.5 \times 10^7$$

That is, 3.5×10^7 years passed between the appearance of the dinosaurs and that of the first birds. Note that 3.5×10^7 is the same as 0.35×10^8

Using scientific notation has one further advantage—it allows us to specify the number of significant figures. For example, we saw in Module 2 that with a number like 860 we have no way of telling whether it is to 2 sf or 3 sf. In scientific notation it would be written as 8.6×10^2 (2 sf) or 8.60×10^2 (3 sf).

Guided Exercise 1 has shown that if numbers use the same powers of ten, subtraction can be carried out in the usual way. It is important to note that this principle is also true for addition. Guided Exercise 2 looks at how to subtract numbers that have different powers of ten.

GUIDED EXERCISE 2: SUBTRACTING NUMBERS THAT HAVE DIFFERENT POWERS OF TEN

How long was it from the time that creatures developed backbones until they evolved into human-like individuals that walked upright? Look back at Table 1 on p. 4 and you can see that the first backboned creatures appeared 4.65×10^8 years ago, and human-like individuals walked upright 2×10^6 years ago.

In longhand, subtracting one figure from the other will give the number of years between creatures developing backbones and walking upright:

$$\begin{array}{r} 465\,000\,000 \\ -\ 2\,000\,000 \\ \hline 463\,000\,000 \end{array}$$

To be able to handle this easily in the powers of ten notation both powers need to be the same with 10^6 as the common unit.

The first backboned creatures appeared 465×10^6 years ago, and the first human-like creatures walked upright 2×10^6 years ago.

Since both numbers have the same power they can be subtracted: $465 - 2 = 463$ which gives 463×10^6 years.

□ Convert 463×10^6 into scientific notation.

■ 4.63×10^8

SAQ 2 Try this subtraction again using 10^8 as the common unit.

SAQ 3 Using the information in Table 1, answer the following questions giving your answers in scientific notation (ignoring significant figures).

(a) When did the first vertebrates appear?

(b) For how long did dinosaurs live on Earth?

(c) When did the first birds appear on Earth?

(d) When did the first human-like individuals appear?

This Section has introduced the concept of geological time and helped you to use scientific notation to express the very long periods of time involved in the evolution of life on Earth. The next Section shows how very short periods of time can be represented in a similar manner, and explains how to multiply and divide powers of ten.

2.4 SHORT TIME PERIODS

You will be familiar with the idea of a day being divided into hours, minutes and seconds. Can you think why time periods that are shorter than one second might need to be measured? One such instance is to measure events that occur very quickly, for example the fluttering of a butterfly's wing.

GUIDED EXERCISE 3: EXPRESSING VERY SMALL NUMBERS IN SCIENTIFIC NOTATION

(a) If a butterfly flutters its wings about 100 times per second, how long does a single flutter take?

If the butterfly flutters its wings 100 times in a second, then the time taken to flutter them once will be 1 second divided by 100, that is:

$$\frac{1}{100} \text{ second}$$

or one-hundredth of a second. As a decimal this could be written as 0.01 second

The power of ten notation can also be used to express a number such as 0.01 which in scientific notation is 1×10^{-2} second, pronounced as 'one times ten to the minus two second'. The value of the power in this example is minus 2 (–2). The figure two represents the number of times that we have divided by 10.

As 100 is 10×10 therefore:

$$\frac{1}{100} = \frac{1}{10 \times 10} = \frac{1}{10^2} = 1 \times 10^{-2}$$

(b) If a humming bird flaps its wings at 1 000 times per second, what is the time taken for one flap?

In 1 second the wings flap 1 000 times. The time taken for one flap therefore is:

$$\frac{1}{1\,000} \text{ second}$$

or one-thousandth of a second. As a decimal this can be expressed as 0.001 seconds. In scientific notation this would be expressed as 1×10^{-3} seconds. The value of the power in this example is minus 3 (–3).

These examples have shown that:

$$\frac{1}{10^2} = 1 \times 10^{-2} \text{ and } \frac{1}{10^3} = 1 \times 10^{-3}$$

In general terms: $1 \times 10^{-\text{power}} = \dfrac{1}{10^{\text{power}}}$

Some more examples are given below:

$$\frac{1}{10\,000} = \frac{1}{10^4} = 1 \times 10^{-4}$$

$$\frac{1}{1\,000\,000} = \frac{1}{10^6} = 1 \times 10^{-6}$$

$$\frac{1}{100\,000} = \frac{1}{10^5} = 1 \times 10^{-5}$$

EXERCISE 1

Table 2 shows a series of numbers both bigger and smaller than 1; try to fill in the numbers that are missing.

TABLE 2 The relationship between numbers and scientific notation

Longhand	10 000		100	10	1		0.01	0.001	
Scientific notation		1×10^3				1×10^{-1}	1×10^{-2}		1×10^{-4}

A completed Table 2 is given in Appendix 2. It is possible that in completing the Table you inserted 1×10^0 and 1×10^1 in the appropriate places without fully understanding what these two powers of ten mean. These two special cases are explained in Section 2.6, but for now look at how to multiply and divide powers of ten.

2.4.1 MULTIPLYING POWERS OF TEN

Multiplying $10^2 \times 10^3$ means 10×10 by $10 \times 10 \times 10$. That is:

$$10^2 \times 10^3 = (10 \times 10) \times (10 \times 10 \times 10) \text{ which} = 100\,000 \text{ or } 10^5 \text{ or } 10^{(2+3)}$$

There are two rules that govern the way in which powers are handled in calculations. The above example illustrates the first rule:

To *multiply* powers of ten *add* the powers.

Some examples are given below:

To multiply $10^4 \times 10^2 = 10\,000 \times 100 = 1\,000\,000 = 10^6$

Using the above rule, add the powers:

$$10^4 \times 10^2 = 10^{(4+2)} = 10^6$$

Another example given in longhand is the multiplying of:

$$10^3 \times 10^1 = 1\,000 \times 10 = 10\,000 = 10^4$$

Again using the rule, adding the powers gives:

$$10^3 \times 10^1 = 10^{(3+1)} = 10^4$$

Finally, $10^5 \times 10^{-2} = 1\,000\,000 \times 0.01 = 1\,000 = 10^3$

Again using the rule to multiply:

$$10^5 \times 10^{-2} = 10^{[5+(-2)]} = 10^{(5-2)} = 10^3$$

The last example has used a basic arithmetical rule about handling a combination of positive and negative numbers that you met in Module 1, Section 8. Recall that when a negative number is added to another number the overall effect is a subtraction: i.e. $12 + (-3)$ is the same as $12 - 3$. When a negative number is subtracted from another number the overall effect is an addition: i.e. $12 - (-3)$ is the same as $12 + 3$.

Try SAQ 4 to check whether you have understood how to multiply powers.

SAQ 4 Calculate the following:

(a) $10^3 \times 10^2 \times 10^1$ (b) $10^4 \times 10^{-3} \times 10^2$ (c) $10^7 \times 10^2 \times 10^0$

Next let us see how to divide powers.

2.4.2 DIVIDING POWERS OF TEN

To divide 10^5 by 10^2 means $10 \times 10 \times 10 \times 10 \times 10$ is being divided by 10×10

$$\frac{10 \times 10 \times 10 \times 10 \times 10}{10 \times 10} = 10 \times 10 \times 10 = 10^3 \text{ or } 10^{(5-2)}$$

From this you can see the second rule about powers:

To *divide* powers of ten *subtract* the powers.

Some examples are given below:

To divide 10^8 by 10^3 in longhand gives:

$$\frac{10^8}{10^3} = \frac{100\,000\,000}{1\,000} = 100\,000 = 10^5$$

Using the rule of subtracting the powers:

$$\frac{10^8}{10^3} = 10^{(8-3)} = 10^5$$

Another example in longhand:

$$10^4 \div 10^1 = \frac{10\,000}{10} = 1\,000 = 10^3$$

Again using the rule of subtracting the powers:

$$\frac{10^4}{10^1} = 10^{(4-1)} = 10^3$$

Finally, in longhand:

$$10^{10} \div 10^{-2} = \frac{10\,000\,000\,000}{0.01} = 1\,000\,000\,000\,000 = 10^{12}$$

Using the rule of subtracting powers:

$$\frac{10^{10}}{10^{-2}} = 10^{[10-(-2)]} = 10^{(10+2)} = 10^{12}$$

Try SAQ 5 to check whether you have understood how to divide powers.

SAQ 5 Calculate the following:

(a) $10^4 \div 10^1$ (b) $10^9 \div 10^{-2}$ (c) $10^6 \div 10^3$

2.5 USE OF THE POWER RULES

The two rules that you learned in Section 2.4 can be used to simplify the manipulation of large numbers. Some examples are given below:

$$10^4 \times 10^{-3} \times 10^2 = 10^{[4+(-3)+2]} = 10^{(4-3+2)} = 10^3$$

$$10^2 \div 10^{-4} = 10^{[2-(-4)]} = 10^{(2+4)} = 10^6$$

Guided Exercise 4 shows how the rules can be used to tackle a problem.

GUIDED EXERCISE 4: MANIPULATING NUMBERS IN SCIENTIFIC NOTATION

It takes 3.6×10^4 seconds for a rocket to get to the Moon. Use this information to work out:

(a) How many minutes it takes for the rocket to get to the moon

(b) How many hours this represents

(a) As there are 60 seconds in a minute, we divide 3.6×10^4 by 6×10^1

$$\frac{3.6 \times 10^4}{6 \times 10^1} = \frac{3.6}{6} \times 10^3 \text{ minutes}$$

Dividing 3.6 by 6 = 0.6 to give: 0.6×10^3 (6×10^2 minutes in scientific notation).

(b) As there are 60 minutes in 1 hour, divide 6×10^2 minutes by 6×10^1

$$\frac{6 \times 10^2}{6 \times 10^1} = 1 \times 10^1 = 10 \text{ hours}$$

Therefore it takes 10 hours for a rocket to get to the Moon.

SAQ 6 Express the answers to the following as single powers of ten:

(a) $10^3 \times 10^{-2} \times 10^4$ (b) $10^{-4} \div 10^1$ (c) $10^8 \times 10^2 \div 10^{-3}$

(d) If it takes 3.6×10^8 seconds for a rocket to get to Mars:

(i) How many minutes does it take?

(ii) How many hours does this represent?

2.6 SPECIAL CASES

Now that you have had some practice in handling powers of ten, let us look back to Table 2. Can you now work out what 10^0 and 10^1 mean? Consider the calculation:

$$10^6 \div 10^5 = 10^{(6-5)} = 10^1$$

In longhand this is:

$$\frac{1\,000\,000}{100\,000} = 10$$

We can see that $10^1 = 10$ It is more usual to write this as 10

Next, consider the calculation:

$$10^3 \div 10^3 = 10^{(3-3)} = 10^0$$

Again, in longhand:

$$\frac{1\,000}{1\,000} = 1$$

You can see that $10^0 = 1$ This is usually written as 1

In fact there are lots of examples for which the answer is 10^0 for example:

$10^7 \div 10^7$, $10^5 \div 10^5$ and so on ...

All we are doing is dividing identical quantities; a number divided by itself always results in 1; for example:

$$\frac{3}{3} = 1$$

It is worth remembering that in any calculation the answer 10^0 is 1

2.7 THE SCALE OF TIME

So far the two extremes of time have been considered—geological times as long as 5×10^9 years ago and the short time of 10^{-3} seconds that it takes a humming bird to flap its wings once. You may be wondering how these very large or small numbers can be entered on your calculator, particularly as you have not yet learnt how to enter superscripts such as 9 and –3 on your calculator. This is achieved by using the exponent key usually marked EXP or EE. The next Guided Exercise demonstrates the use of the EXP or EE key on your calculator.

GUIDED EXERCISE 5: HANDLING POWERS OF TEN USING A CALCULATOR

How many hours would it take a space rocket to reach the Moon if the rocket is travelling at 5 000 metres per second and the Moon is 405 000 000 metres away? In order to tackle this question you need to remember the relationship between time, distance and speed that you met in Module 2. This was given as:

$$\text{speed} = \frac{\text{distance}}{\text{time}} \text{ which is equivalent to: } \text{time} = \frac{\text{distance}}{\text{speed}}$$

(Remember that s is the standard abbreviation for second, m is for metres and **speed** is m/s.)

Expressing our problem in scientific notation, with the units included, gives:

$$\text{time(s)} = \frac{4.05 \times 10^8\,\text{m}}{5.00 \times 10^3\,\text{m/s}}$$

BOX 1

Press	4	
press	•	
press	0	
press	5	
press	EXP or EE	(4.05 00 or 4.05^{00} should appear)
press	8	(4.05 08 or 4.05^{08} should appear)

BOX 2

Press	÷	(4.05 08 or 4.05^{08} or 405000000 should appear)
press	5	(5 should appear)
press	EXP or EE	5. 00 or 5^{00} should appear)
press	3	(5. 03 or 5^{03} should appear)
press	=	(8.1 04 or 8.1^{04} or 81000 should appear)

BOX 3

Press	÷	
press	6	
press	0	
press	=	(1.35 03 or 1.35^{03} or 1350 should appear)

BOX 4

Press	÷	
press	6	
press	0	
press	=	(2.25 01 or 2.25^{01} or 22.5 should appear)

BOX 5

Press	5	
press	•	
press	6	
press	EXP or EE	
press	9	(5.6 09 or 5.6^{09} should appear)

Note that the metres on the top of the fraction and on the bottom of the fraction 'cancel' (divide) out. This is explained later, for now just accept this. Consequently this leaves s as the unit of time for the answer.

Have a go at working out the answer without your calculator by handling the powers of ten first and remembering that you subtract the powers when dividing powers of ten.

$$\text{time} = \frac{4.05}{5} \times 10^{(8-3)}\ \text{s}$$

$$\text{time} = \frac{4.05}{5} \times 10^{5}\ \text{s}$$

and then divide 4.05 by 5

$$\text{time} = 0.81 \times 10^{5}\ \text{s}$$

Expressing this in scientific notation, the answer becomes:

$$\text{time} = 8.1 \times 10^{4}\ \text{s}$$

To work this out on your calculator you will need to use the EXP or EE key, which allows you to enter a number that is expressed in the powers of ten notation. Try to work through the steps using your calculator. The keys you need to press are shown in Boxes 1–4.

Step 1 Enter 4.05×10^8, following the instructions in Box 1. You will see from Box 1 that it is not necessary to press the ten and times keys—the EXP or EE key automatically takes care of these and you just enter the power, in this case 8.

Step 2 Divide the distance (the 4.05 08 or 4.05^{08} displayed on your calculator) by the speed, as shown in Box 2. When reading the answer on your calculator display you need to remember to incorporate the multiplication sign and the ten with the power. Expressed in scientific notation, the answer is that the journey takes 8.1×10^4 seconds for the rocket to reach the Moon.

Step 3 It is easier to understand this journey time in hours and minutes. As there are 60 seconds in one minute, divide by 60. The keys you need to press to convert the 8.1 04 or 8.1^{04} or 81 000 on your display to minutes are shown in Box 3.

The number of minutes the journey takes is therefore 1.35×10^3

Step 4 To convert to hours, divide by 60 again. Box 4 shows which keys to press. The number of hours the journey takes is therefore 2.25×10^1 or 22.5 hours. The essential point to remember when entering powers of ten into a calculator is to enter the number and the power but *not* the 'times 10'. The keys to press if we want to enter 5.6×10^9, for example, are shown in Box 5. The EXP or EE function automatically handles the times 10; if you try to enter '× 10' you will alter the calculation by a factor of 10. This also applies to a number such as 10^3 (1 000). Since this means 1×10^3 the keys you press are 1, EXP, 3 and *not* 10, EXP, 3. Similarly when reading off your display you need to remember to replace the multiplication sign and the power of 10.

i.e. 5.6 09 or 5.6^{09} means 5.6×10^9

The next exercise gives more practice in handling powers of ten.

GUIDED EXERCISE 6: CALCULATING THE TIME IT TAKES LIGHT TO TRAVEL FROM THE FRONT TO THE BACK OF YOUR EYE

How long does it take light travelling at 3.0×10^8 m/s to pass from the front to the back of a human eye, a distance of 7.5 mm?

Before starting a question like this it is essential to ensure that all of the data are in the same units. The speed is given in metres per second (m/s), but the distance

is in millimetres (mm), so we need to convert millimetres to metres. Recall from Module 2 that a millimetre is one-thousandth of a metre, that is:

$$1 \text{ mm} = \frac{1}{1\,000} \text{ m or } 0.001 \text{ m or } 10^{-3} \text{ m}$$

So the distance from the front to the back of a human eye in metres is:

$$7.5 \times 10^{-3} \text{ m}$$

Using the relationship between time, speed and distance:

$$\text{time} = \frac{\text{distance}}{\text{speed}} \text{ so time} = \frac{7.5 \times 10^{-3} \text{ m}}{3.0 \times 10^{8} \text{ m/s}}$$

As in the last Guided Exercise let us first work out the answer without a calculator.

Handle the powers first:

$$\text{time} = \frac{7.5}{3.0} \times 10^{(-3-8)} \text{ s} = \frac{7.5}{3.0} \times 10^{-11} \text{ s}$$

and then divide 7.5 by 3.0

$$\text{time} = 2.5 \times 10^{-11} \text{ s}$$

Before we can do the calculation using a calculator, it is important to notice that there are negative powers to deal with. In order to enter these into the calculator you need to use the +/– key, introduced in Module 1. The key changes the sign on the display, if you press it several times you will see the minus sign displayed and then disappear as you effectively change back from – to +. You learnt in Module 1 that to input negative numbers on your calculator you must input the number and then the – sign. The same is true for negative powers; so the order is EXP, number, +/– key. Using your calculator, and following the steps in Box 6 as a guide, work out the answer to the question again. Expressing the final figure on your display in scientific notation, it would be written as: 2.5×10^{-11} seconds. This is the very short period of time that it takes light to travel from the front to the back of the human eye.

BOX 6

Press	7	
press	•	
press	5	
press	EXP or EE	(7.5 00 or 7.5^{00} should appear)
press	3	(7.5 03 or 7.5^{03} should appear)
press	+/–	(7.5–03 or 7.5^{-03} should appear; note that the + power has changed to a – power)
press	÷	
press	3	
press	EXP or EE	(3. 00 or 3^{00} should appear)
press	8	(3. 08 or 3^{08} should appear)
press	=	(2.5–11 or 2.5^{-11} should appear)

2.8 REPRESENTATION OF UNITS

In Module 2, you learned the numbers that are measurements of time, distance, area or volume for example, *always* need to have their units of measurement specified in order for the number to have any meaning.

Units can be written down in a number of different ways. For instance the area of a rectangle having the dimensions 3 metres by 2 metres can be calculated as:

area = 3 metres × 2 metres = 6 metres × metres
or as: area = 3 m × 2 m = 6 square metres

We would pronounce the answer as 'six square metres', but would write it down as: metres^2, or m^2 (see Module 3), where the power of 2 represents the multiplication of metres by metres.

The link between the powers notation and handling units can be further demonstrated by looking at the units involved in calculating volume, for example:

volume = length (m) × width (m) × depth (m) the units of
volume = m × m × m which expressed as a power = m^3.

This is equivalent to $10 \times 10 \times 10$ being written as 10^3. The units of a calculation are being treated in exactly the same way as the numbers. The same

principle is true in the calculation of speed from known measurements of distance and time. To work this out involves the relationship:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

So if an object travels 24 metres in 8 seconds, its speed is calculated as:

$$\text{speed} = \frac{24\,\text{m}}{8\,\text{s}} = 3\,\text{m/s}$$

which we would describe as having a speed of 3 metres per second. In the course so far we have written this as m/s, where the '/' represents the division of metres by seconds, but there is an alternative method using powers that is more concise.

You will recall from Section 2.4 that a negative power represents the number of times 1 is divided by 10.

☐ Express the following fractions in scientific notation:

$$\frac{1}{10} \text{ and } \frac{1}{10^2}$$

■ 10^{-1} and 10^{-2}

Note in passing that 1/10 is called the *reciprocal* or the *inverse* of 10. Similarly 1/100 is the reciprocal (or inverse) of 100. So to get the reciprocal of 100 you put 1 over it to give 1/100. You know that 1/100 is 10^{-2} and that 100 is 10^2 therefore the reciprocal of 10^{-2} (1/100) is 10^2 (100). So to get the reciprocal of 10^{-2} you simply change the sign of the power to 10^2. You can practise finding the reciprocal of any number by using the $1/x$ key on your calculator.

Using powers of 10 to represent large or small numbers is very convenient but the use of power notation is not just limited to powers of ten; it can be used to represent the multiplication of any number by itself any number of times. For example:

2×2 could be written 2^2 and

$5 \times 5 \times 5$ could be written 5^3

☐ Express $4 \times 4 \times 4 \times 4$ and 6×6 in power notation

■ 4^4 and 6^2

Particularly useful is the way in which a negative power is used to represent the number of times something is divided into 1. For example:

$$\frac{1}{6 \times 6 \times 6} = \frac{1}{6^3} = 1 \times 6^{-3}$$

$$\frac{1}{12} = \frac{1}{12^1} = 1 \times 12^{-1}$$

☐ Express the following fractions in scientific notation:

$$\frac{1}{5 \times 5} \text{ and } \frac{1}{3 \times 3 \times 3}$$

■ 1×5^{-2} and 1×3^{-3}

Units can be treated using power notation in the same way.

☐ If an answer had units of $\frac{1}{\text{s}}$ how could this be simplified using scientific notation?

■ s^{-1} is a simpler way of writing $\frac{1}{\text{s}}$

□ If an answer had units of $\frac{1}{m^2}$ how could this be simplified using scientific notation?

■ m^{-2} is simpler.

Now return to the units of speed:

$$\text{speed} = \frac{\text{distance (m)}}{\text{time (s)}}$$

□ Can you suggest an alternative form to $\frac{m}{s}$ using the scientific notation?

■ The units of speed could be written $m\,s^{-1}$.

This method of using powers is the most widely accepted way of writing units and this will be used in *Into Science*.

Have a go at SAQ 7 on powers before tackling the revision in SAQ 8.

SAQ 7

(a) Simplify the following expressions using the powers notation.

(i) $3 \times 3 \times 3$ (ii) $m \times m \times m$ (iii) $\frac{1}{9 \times 9}$

(iv) $\frac{1}{m \times m}$ (v) $\frac{6 \times 6 \times 6}{4 \times 4}$

Express the units of the following quantities in (b) and (c) in a scientific way.

(b) Density is given by mass ÷ volume, that is:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

If mass is measured in kilograms (kg) and length is measured in metres (m), what are the units of density?

(c) **Acceleration** is the rate of change of speed and can be expressed as:

$$\text{Acceleration} = \frac{\text{speed}}{\text{time}}$$

If speed has units of distance ÷ time ($m\,s^{-1}$) and time has units of seconds (s), what are the units of acceleration?

SAQ 8

(a) If Concorde flies at $551\ m\,s^{-1}$, how long does a journey to the USA take if it is 4.11×10^6 m away? Give your answer to three significant figures.

(b) How long does it take a spacecraft travelling at 8 kilometres per second ($km\,s^{-1}$) to travel from Mars to Jupiter, a distance of 500 000 000 km? Give the answer to three significant figures.

(c) What is the average speed of a car in $m\,s^{-1}$, if it takes 1 hour and 25 minutes to travel 120 km from Birmingham to Milton Keynes? Give the answer to three significant figures.

(d) If light travels at $3 \times 10^8\ m\,s^{-1}$ how long does a torch beam take to reach a wall 3 m away?

In this Section you have had the opportunity to use your calculator to handle powers of ten and to work out the times of a variety of events. Section 3 extends this work on powers of ten, using a range of measurements of distance.

3 DISTANCES

How far is the Earth from the Sun? How big is our Solar System? What is the smallest item in the world? These are just some of the questions about distance that a scientist may be concerned with. This Section considers a range of distances. Once again, you are not expected to remember the measurements, which are included to give you an impression of the scale.

3.1 OUR SOLAR SYSTEM

Let us first examine our Solar System, shown in Figure 2, and look at the arrangement of the major planets.

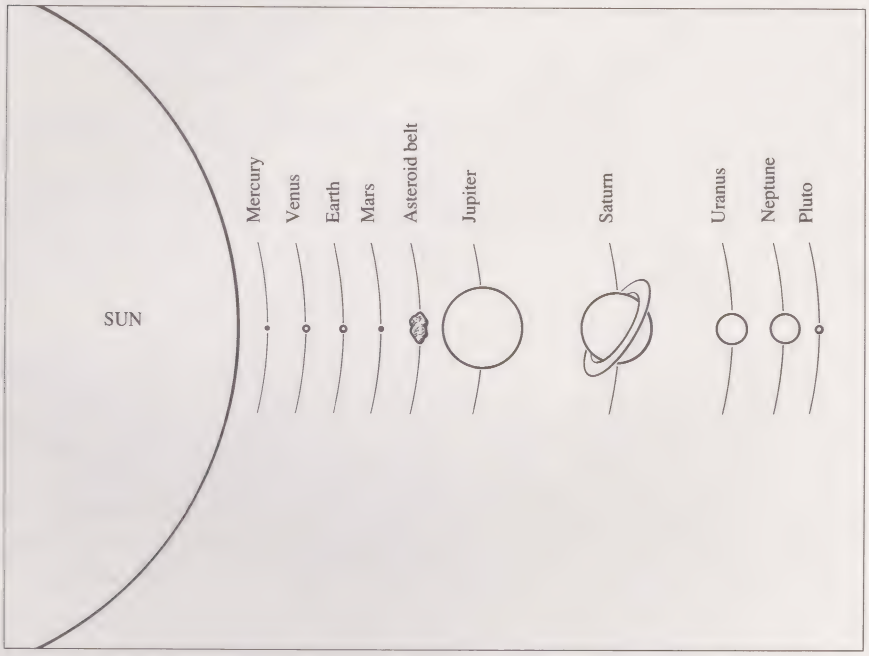

FIGURE 2 Our Solar System.

The relative sizes of the Sun and the planets, together with the relative distances between Sun and planets are shown in Figure 2; but you should note that some of the planets are so far from the Sun that it is not possible to draw the **interplanetary** distances to scale. The Earth is just one small planet in the Solar System, which in turn is just one such system within the Milky Way or Galaxy (which consists of 1×10^{11} stars). Our Galaxy takes the form of a huge disc, with a slight bulge in the middle, as shown in Figure 3.

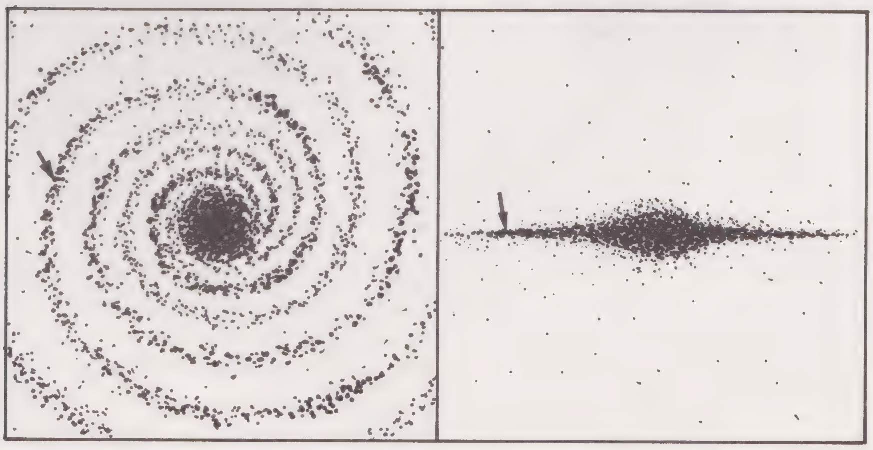

FIGURE 3 The appearance of our Galaxy (a) from the top and (b) from the side. The small arrow indicates the location of our Solar System, within the Galaxy.

How large is our Galaxy? As you can imagine, the metre is not really a very suitable unit in which to express vast astronomical distances. A unit of distance called the **light-year** is often used for astronomical measurements. A light-year is the distance that light travels in one year.

Let us calculate the distance of a light-year in metres. To do this you need to know that the speed of light is $3.0 \times 10^8\,\mathrm{m\,s^{-1}}$. This means that in 1 second light travels: $3.0 \times 10^8\,\mathrm{m}$

In 1 minute (60 seconds) therefore light travels: $3.0 \times 10^8 \times 60\,\mathrm{m}$

In 1 hour light travels: $3.0 \times 10^8 \times 60 \times 60\,\mathrm{m}$

In 1 day light travels: $3.0 \times 10^8 \times 60 \times 60 \times 24\,\mathrm{m}$

In 1 year therefore light travels:

$$3.0 \times 10^8 \times 60 \times 60 \times 24 \times 365\,\mathrm{m} = 9.4608 \times 10^{15}\,\mathrm{m}$$

$$= 9.5 \times 10^{15}\,\mathrm{m}\ \text{(to 2 sf)}$$

Therefore a light-year is 9.5×10^{15} m, about 5 000 billion miles.

Astronomers have estimated the size of our Galaxy to be 100 000 light-years in diameter and 10 000 light-years from top to bottom. Within this system, the Sun and its Solar System have been accurately measured to occupy a position about 30 000 light-years from the centre. The small arrows in Figure 3 show the position of the Solar System.

All the stars in the Universe seem to be organized into galaxies, and the galaxies themselves appear to form scattered clusters. Our Galaxy belongs to the so-called local group, a cluster that contains 17 other galaxies. Some other clusters are at least 3×10^9 light-years away, and a number of very bright, single galaxies have been observed that may be as far as 2×10^{10} light-years away. Whenever a new, more powerful telescope is built, yet more galaxies are revealed at even greater distances. Thus the Earth appears to be surrounded by a Universe without any known boundary.

You may be wondering how scientists know so much about the world we live in; the next Section will try to answer this question.

3.2 A CLOSER LOOK AT THE UNIVERSE

Light is the key to our detailed knowledge of the Universe. Light received from objects far out in space has helped scientists discover what lies within that part of the Universe that surrounds the Earth. Almost all the stars, planets and moons either **radiate** or **reflect** light.

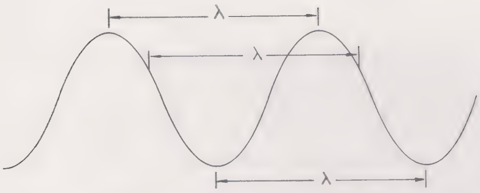

FIGURE 4 Schematic illustration of a wave. The wavelength is indicated by the Greek letter λ (lambda, pronounced lam-da). This shorthand way of representing a wavelength is often used in science.

But what is light? In science the term light is used to mean something more than the light that we can see with our eyes. It refers to a special kind of energy that can travel through space in the form of waves. Some of the waves such as X-rays, ultraviolet, infrared and radio waves, are invisible. Figure 4 shows a wave. The various types of wave are usually described according to their **wavelength**. The wavelength is the distance between two successive identical points on a wave pattern measured in a horizontal direction; a wavelength can be measured from crest to crest, trough to trough, or from any other two points, as shown in Figure 4.

Figure 5 shows a range of wavelengths of light. Some of the longest known wavelengths are radio waves; different broadcasting stations transmit at different wavelengths. Moving along the range to shorter wavelengths are microwaves, the infrared range and visible light. Visible light is made up of wavelengths from about 0.000 0004 m, or 4×10^{-7} m, to about 0.000 0007 m, or 7×10^{-7} m. Smaller wavelengths include the range of ultraviolet, and then X-rays at about 10^{-8} m. The complete range of known wavelengths extends from 3×10^7 m to 3×10^{-17} m.

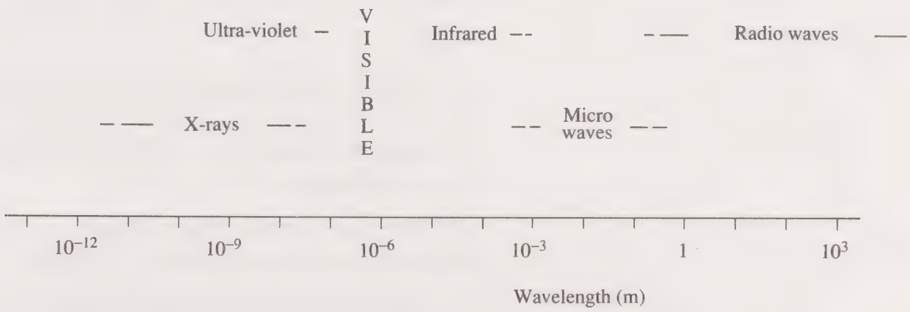

FIGURE 5 Part of the range of wavelengths of light.

Do all these different wavelengths travel at the same speed? In order to answer this, try the following questions, calculating the speed in $m\,s^{-1}$

□ (a) If it takes light 500 s to travel the 150 000 000 km from the Sun, how fast is the light travelling?

(b) A weather satellite orbits the Earth at a height of 36 000 km. If it takes a beam of light only 0.12 s to reach it how fast is the light wave travelling?

(c) A star is 6×10^{12} km away from the Earth; if it takes 2×10^{7} s for light from the star to reach us, how fast is the light travelling?

(d) Using a satellite in space to transmit a telephone signal to the USA results in a journey of 450 000 000 m and it takes 1.5 s. (This can be noticed as a time delay in conversation.) How fast does this wave travel?

■ All the answers give the speed of light as $3 \times 10^{8}\,m\,s^{-1}$. From this small sample we can conclude that different wavelengths of light travel through space at one speed.

The scientific observation you have just made is an extremely important one. In fact, scientists have found that nothing can travel faster than the speed of light.

This Section has encompassed distances ranging from those between the galaxies to those between individual wavelengths of light. The next Section will try to give you a feel for the size of one of the smallest particles in existence: an **atom**.

3.3 VERY SMALL DIMENSIONS

It is relatively easy to visualize measurements in metres, centimetres and millimetres; but what about smaller dimensions? So that you can get a feel for the very small, this Section looks at water: what does it consist of and what is the smallest unit from which it is made? Your initial response to this question may be that water is made up of droplets, so let us start by measuring the size of a droplet.

GUIDED EXERCISE 7: MEASURING THE SIZE OF A WATER DROPLET

How would you measure the volume of a droplet of water? If you look at a water droplet on a work surface, you can see that although the droplet may be a uniform shape, trying to obtain measurements from which to work out its volume is a difficult prospect. A direct measurement is not possible because touching the droplet in any way would almost certainly disturb it, and change its dimensions. However, there is an alternative method: you could use a practical

method of counting the number of droplets that fill a container of a known volume.

To measure a small quantity of water you will need a 5 millilitre (abbreviated to ml) measuring spoon. This can be either a kitchen measuring spoon, or one supplied with a bottle of medicine—5 ml is a standard dose, and is equivalent to 5 cubic centimetres (cm^3).

1 Turn on a tap so that it is set at a steady slow drip. You may need to experiment with it to ensure a dripping rate at a pace that you can count.

2 Hold the measuring spoon beneath the tap and count the number of droplets needed to fill it.

3 Carry out the activity at least six times, entering the data in Table 3.

4 Work out the average of the readings, and enter your results in Table 3. Our results are already entered on the second column of the table. In all of the calculations it is assumed that the spoon is *exactly* 5 cm^3.

TABLE 3 Number of droplets needed to fill a 5 cm^3 spoon

Number of droplets	Our data	Number of droplets	Your data
1	41	1	
2	39	2	
3	38	3	
4	40	4	
5	38	5	
6	38	6	
Total	234	Total	
Average	39	Average	

Since 5 ml is equivalent to 5 cm^3, then 39 droplets in 5 ml is the same as 39 droplets in 5 cm^3. To determine the volume occupied by one droplet, divide the volume occupied (5 cm^3) by the number of droplets (39):

$$= \frac{5\,cm^3}{39}$$

□ Use your calculator to work out the answer in scientific notation (to two significant figures).

■ $\frac{5\,cm^3}{39} = 0.13\,cm^3$ or in scientific notation $1.3 \times 10^{-1}\,cm^3$

How do we convert $1.3 \times 10^{-1}\,cm^3$ to m^3?

To see what happens when cubic centimetres are converted to cubic metres it is worthwhile trying to visualize what a cubic centimetre actually looks like.

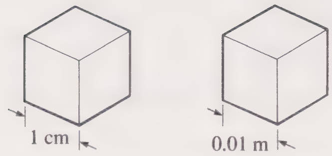

FIGURE 6 (a) A cube with sides of 1 cm. (b) The same cube, but with the measurements expressed in metres. The sides are now 0.01 m, or 10^{-2} m.

Figure 6a shows a cube with sides of exactly 1 centimetre. Figure 6b shows the same cube, but with sides expressed in metres. As there are 100 centimetres in 1 metre, centimetres can be converted to metres by dividing by 100:

$$1\,cm = \frac{1}{100}\,m$$

This is equal to 0.01 m or 10^{-2} m

The volume of the cube in Figure 6a is therefore:

$$1\,cm \times 1\,cm \times 1\,cm = 1\,cm^3$$

The volume of the cube in Figure 6b is therefore:

$$1 \times 10^{-2}\,m \times 1 \times 10^{-2}\,m \times 1 \times 10^{-2}\,m$$

Handling the powers first gives:

$$1 \times 1 \times 1 \times 10^{(-2-2-2)}\,\text{m}^{(1+1+1)} = 1 \times 10^{-6}\,\text{m}^3$$

Therefore, $1\,\text{cm}^3$ equals $1 \times 10^{-6}\,\text{m}^3$.

The volume of the water droplet from our experiment expressed in cubic metres is therefore:

$$1.3 \times 10^{-1} \times 10^{-6}\,\text{m}^3 \text{ which is:}$$

$$1.3 \times 10^{-7}\,\text{m}^3$$

SAQ 9 Using your data calculate the volume of *your* droplet of water in cubic metres.

3.4 EVEN SMALLER DIMENSIONS

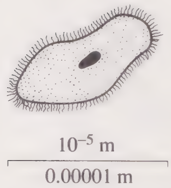

FIGURE 7 A paramecium can be seen in water when a droplet is magnified 1 000 times.

The value calculated for the volume of a water droplet may seem very small, but in terms of the scale of scientific measurement it is relatively large. Let us consider a water droplet more closely to see what water is made up of.

To the naked eye a droplet of pond water appears to be clear and smooth. When it is magnified about one thousand times it still appears relatively smooth, but here and there very tiny things shaped like rugby balls can be seen darting about. These are single celled organisms called paramecia (see Figure 7): they are about 10^{-5} m long, and can only be seen with the aid of a microscope.

If we were able to continue magnifying our water droplet until it no longer has a smooth surface we see something similar to that shown in Figure 8. The blobs shown in the diagram are about 10^{-10} m in size and are called atoms. One way of trying to visualize the size of an atom is to imagine an apple magnified to the size of the Earth; an atom would be roughly the size of the original apple.

Figure 8 shows an important aspect of water, namely that it is composed of two types of atoms: hydrogen atoms (the very small white ones) and oxygen atoms (the larger black ones). Answer the following questions by looking at Figure 8.

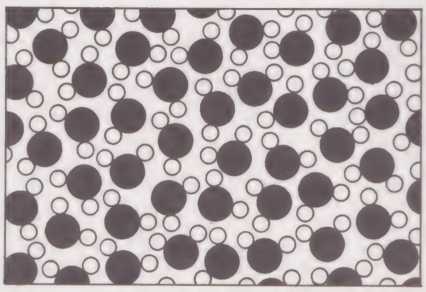

FIGURE 8 The individual atoms in water that could be seen if the drop was magnified 10^9 times. The white atoms are hydrogen, and the black ones oxygen.

□ How many hydrogen atoms are there compared to oxygen atoms?

■ There are twice as many hydrogen atoms as oxygen atoms.

The fact that water is made up from two hydrogen atoms and one oxygen atom is an important one. Atoms are the basic building blocks of *all* material, whether the material is natural, such as rocks, plants and animals, or synthetic, such as plastic; you will learn much more about the different types of atoms in Modules 5 and 6.

Table 4 illustrates the scale of size in science. Notice how useful it is to be able to write very large and very small numbers in scientific notation.

TABLE 4 Some examples of size and distance in science.

Light-years	Metres	Features
	10^{27}	
10^9		furthest detectable stars
	10^{24}	
10^6		distance to the nearest galaxy
	10^{21}	
10^3		distance to the centre of our Galaxy
	10^{18}	
1		distance to the nearest star
	10^{15}	
	10^{12}	
		distance to the Sun
	10^9	
		distance to the Moon
		diameter of the Earth
	10^6	
	10^3	
	1	average height of a 4 year old child
		size of a water droplet
	10^{-3}	
		size of a paramecium
	10^{-6}	
		wavelengths of visible light
	10^{-9}	
		diameter of an atom
	10^{-12}	

4 OVERVIEW

SUMMARY

These are the concepts that you have learnt about in this Module:

- Geological time is the term used to express the period of time since the Earth came into existence.
- The large distances involved in astronomical measurement are measured in a unit called the light-year.
- There are many different types of light; they are distinguished by individual wavelengths.
- Atoms are the basic building blocks of all materials.
- The speed of light is a constant for all wavelengths and is equal to $3 \times 10^8\ \mathrm{m\,s^{-1}}$. Nothing can go faster than this speed.

SKILLS

Now that you have completed this Module, you should be able to:

- express numbers in scientific notation
- perform calculations using scientific notation, without a calculator, and with a calculator using the EXP or EE key
- convert units of time between hours, minutes and seconds.

APPENDIX 1: EXPLANATION OF TERMS USED

As you progress through the Modules you will meet some of these terms again and learn more about them.

ACCELERATION Is the rate at which speed changes with time.

ATOM One of the basic building blocks of all materials. A very small particle which is about 10^{-10} m in diameter.

BACTERIA Very small simple organisms that occur in enormous numbers everywhere in nature.

GALAXIES Independent groups of millions of stars within the Universe. A galaxy may contain many solar systems within it.

GALAXY Written with a capital G, this refers to our own Galaxy, called the Milky Way; other galaxies have a small g.

GEOLOGICAL TIME Time spanning the millions of years since the Earth came into existence.

INTERPLANETARY Between individual planets.

LIGHT A general term for many types of energy that can travel as a wave.

LIGHT-YEAR The distance that light travels in one year.

MILKY WAY The name for the group of stars to which our own Solar System belongs. It is otherwise known as our Galaxy.

PLANET A body that orbits the Sun or another star.

POWERS OF TEN A shorthand notation used to express numbers by the use of powers of ten. It is particularly useful when expressing large or very small numbers. 10^6 is pronounced 'ten to the power six' or often just 'ten to the six'.

RADIATE To give off light from a surface. The Sun, for example, radiates light.

REFLECTS When light waves effectively bounce off a surface, the direction in which they are travelling changes abruptly. This process is known as reflection. Moonlight, for example, is actually light that originally came from the Sun, but has been reflected by the Moon's surface.

SCIENTIFIC NOTATION A way of expressing a number so that there is only one non-zero digit to the left of the decimal point; the remaining digits are expressed as powers of ten.

SPEED The distance travelled in a specified time.

SOLAR SYSTEM The bodies (notably the planets and the moons) that circle the Sun. Without capital letters it refers to other solar systems.

UNIVERSE The totality of everything that exists.

WAVELENGTH Is the distance between two successive, identical points on a wave pattern.

APPENDIX 2

The completed Table 2 is given below:

Longhand	10 000	1 000	100	10	1	0.1	0.01	0.001	0.000 1
Scientific notation	1×10^4	1×10^3	1×10^2	1×10^1	1×10^0	1×10^{-1}	1×10^{-2}	1×10^{-3}	1×10^{-4}

SAQ ANSWERS AND COMMENTS

SAQ 1

(a) 3.75×10^9 (b) 2.5×10^8 (c) 6.5×10^5

(d) 4×10^6 (e) 3×10^3

SAQ 2 4.63×10^8 years

Using 10^8 as the common unit, the subtraction becomes:

$$4.65 \times 10^8 - 0.02 \times 10^8$$

That is $(4.65 - 0.02) \times 10^8$

Expressed in scientific notation the answer is:

$$4.63 \times 10^8 \text{ years}$$

SAQ 3

(a) 4.65×10^8 years ago
(b) $2 \times 10^8 - 0.65 \times 10^8 = 1.35 \times 10^8$ years
(c) 1.65×10^8 years ago
(d) 2×10^6 years ago

SAQ 4

(a) $10^{(3+2+1)} = 10^6$
(b) $10^{(4-3+2)} = 10^3$
(c) $10^{(7+2+0)} = 10^9$

SAQ 5

(a) $10^{(4-1)} = 10^3$
(b) $10^{[9-(-2)]} = 10^{(9+2)} = 10^{11}$
(c) $10^{(6-3)} = 10^3$

SAQ 6

(a) $10^{[3+(-2)+4]} = 10^5$
(b) $10^{[-4(-1)]} = 10^{-5}$
(c) $10^{[8+2-(-3)]} = 10^{(8+2+3)} = 10^{13}$
(d)

(i) $\dfrac{3.6 \times 10^8}{6 \times 10^1}$ seconds $= 6 \times 10^6$ minutes

(ii) $\dfrac{6 \times 10^6}{6 \times 10^1}$ minutes $= 1 \times 10^5$ hours

SAQ 7

(a) (i) 3^3 (ii) m^3 (iii) 9^{-2} (iv) m^{-2} (v) $6^3 \times 4^{-2}$
(b) Units of density kg m^{-3}

$$\frac{\text{mass}}{\text{volume}} = \frac{\text{kg}}{\text{m} \times \text{m} \times \text{m}} = \frac{\text{kg}}{\text{m}^3} = \text{kg m}^{-3}$$

(c) Units of acceleration m s^{-2}

$$\frac{\text{speed}}{\text{time}} = \frac{\text{m s}^{-1}}{\text{s}} = \text{m s}^{[-1(-1)]} = \text{m s}^{-2}$$

SAQ 8 All the parts of this question use the equation

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

(a)

$$\text{time} = \frac{4.11 \times 10^6\,\text{m}}{551\,\text{m s}^{-1}} = 7459.165\,154\,\text{s}$$

To three significant figures therefore the answer is:

$$= 7.46 \times 10^3\,\text{s}$$

(b)

$$\text{time} = \frac{5 \times 10^8\,\text{km}}{8\,\text{km s}^{-1}} = 6.25 \times 10^7\,\text{s}$$

As *both* distances are in kilometres there is no need to convert the units to metres; the answer is in seconds.

(c) $23.5\,\text{m s}^{-1}$ To convert 120 km to m you multiply by 10^3 i.e. the distance in metres $= 120 \times 10^3$ m.
To convert 1 hour and 25 minutes to minutes, there are 60 minutes in an hour therefore in total the journey took 85 minutes.

In seconds $85 \times 60\,\text{s} = 5.1 \times 10^3\,\text{s}$

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{120 \times 10^3\,\text{m}}{5.1 \times 10^3}.$$

$\text{speed} = 23.529\,\text{m s}^{-1}$

$= 23.5\,\text{m s}^{-1}$ (to 3 significant figures.)

(d)

$$\text{time} = \frac{3\,\text{m}}{3 \times 10^8\,\text{m s}^{-1}} = 1 \times 10^{-8}\,\text{s}$$

SAQ 9 If you have any problems with this, look back through our calculations and try to find out where you are going wrong.